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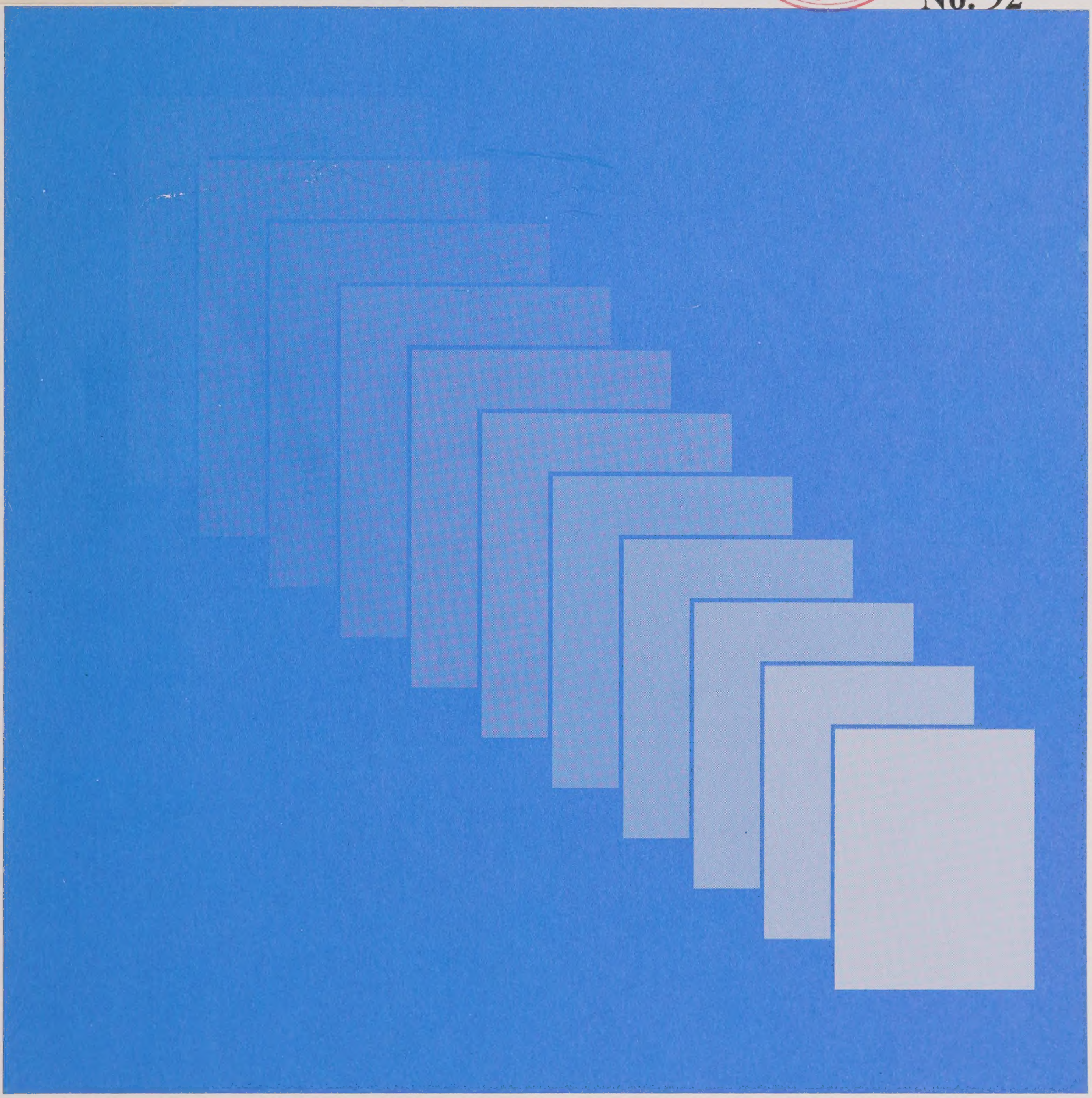

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This paper represents the views of the authors and does not necessarily reflect the opinions of Statistics Canada.

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Abstract

This study is one of a series that examines how technology adoption affects the skills of workers. Previous papers in the series have approached this issue in different ways with data from a variety of sources. Using data on the strategies and activities of small and medium-sized firms in both manufacturing and services industries, Baldwin and Johnson (1995), Baldwin, Johnson and Pedersen (1996) examine the connection between the different strategies that are pursued by growing firms. Firms that stress technological competencies are found to also place a greater emphasis on skill enhancement and training activities. Using survey data on the type of technology used in manufacturing plants and plant managers' perceptions of the skill requirements and training costs associated with the adoption of new technologies, Baldwin, Gray and Johnson (1995) find that technology use leads to greater skill requirements, more training, and higher training costs.

This paper uses survey data on the incidence of advanced technology adoption and matched panel data on plant characteristics such as wages, capital intensity, and size to examine the connection between technology use and the wage rates received by workers. Since higher wages are associated with higher skill levels, establishing a connection between technology use and wages reinforces the earlier findings.

Key words: Innovation, Technology, Wages and Skills

Introduction

This paper uses survey data on the incidence of advanced technology adoption and matched panel data on plant characteristics such as wages, capital intensity, and size to examine the connection between technology use and the wage rates received by workers. Since higher wages are associated with higher skill levels, establishing a connection between technology use and wages reinforces earlier findings of technology-skill relationships.

Since 1980, wage differences between skilled and unskilled workers have widened in North America. Since technology-induced shifts in the demand for labour may be responsible for some of this change in the wage structure, the paper also examines whether the connection between the wage structure and technology has changed during the 1980s. Previous studies that have examined the effect of technological change on the demand for skilled workers have focused on a related question; but they have tended to use indirect measures of changes in technology. Both Lillard and Tan (1986) and Mincer (1992) examine the relationship between technological change and human resource requirements by correlating measures of multi-factor productivity with measures of the intensity of training. Bartel and Lichtenberg (1987) focus on the relationship between capital stock and the proportion of the labour force with higher education. Berman, Bound and Griliches (1994) relate the share of the total wage bill accounted for by higher skilled non-production workers to industry research and development expenditure and the share of new investment that is spent on computers.

Most of these studies are done at the industry level and do not allow for an examination of changes at the plant level. Previous studies have also used very rough measures of the technological base of an industry. This paper uses micro-economic rather than aggregate industry data to explore the relationship between technology and the wage structure and uses more detailed measures of technology at the plant level–the numbers of advanced technologies in use and the type of technology in use taken from a survey on advanced manufacturing technologies. These are then combined with micro-economic plant data taken from the Canadian Census of Manufactures to measure other plant characteristics that are used in the wage equations.

1. The Wage Structure and Technology Use

Over the past twenty years, individual wage rates have become polarized in both Canada (Beach and Slotsve, 1994; Morissette, Myles and Picot, 1994) and in the United States (Levy and Murnane, 1992). There is a disagreement over the primary causes of this change.

Some have argued that there has been a shift in the demand for skilled as opposed to unskilled labour as a result of globalization (Wood, 1994). Models of international trade predict that relative factor prices in developed and developing countries will tend to equalize when tariffs are lowered. Because of higher import penetration from developing countries, the wage rates of lower-skilled workers in western countries are seen to be increasingly affected by the wages of workers in developing nations.

The case in favour of the importance of trade involves both empirical and theoretical arguments. The empirical estimates of Wood (1995) have been aimed at showing that the magnitude of the trade effect is large. Others have invoked trade theory to argue that the wage structure (relative factor prices) is determined in world markets and by differences in domestic productivity across sectors. In this world, relative domestic factor supplies are not important, nor is general labour-augmenting technical progress. Relative wages can be affected by technological change only if it involves differential changes in the rate of technical progress across sectors.[1]

While pressures for factor-price equalization may be having an impact on the wages of unskilled workers, the evidence to support the extreme form of the theory (exact factor price equalization) is not persuasive. As Freeman (1995, p. 22) notes, there is a convincing body of evidence from empirical labour economics that domestic developments affect domestic wage structures. Changes in both the domestic supply of and demand for labour have impacted on the wage structure.

Others have argued that earnings polarization is affected both by shifts in the domestic (North American) supply of relative quantities of skilled and unskilled labour over the last decade as well as changes in demand brought about by technical change (Murphy and Welch, 1992; Katz and Murphy, 1992). While the relative supply of skilled workers is seen to have played a key role in affecting the wage structure, so too is a steady growth in the relative demand for more educated workers. Skill-biased or skill-augmenting technical change is offered as a likely explanation for these changes in labour demand.

A similar story is told by Berman, Bound and Griliches (1994), using the relative wages of non-production and production workers in manufacturing to represent remuneration rates for more and less-skilled workers. Although the wages of the skilled category have been increasing, their share of employment has also been increasing. Once more, this trend is compatible with the existence of skill-augmenting technical change that has been increasing the demand for relatively more skilled workers.

Davis and Haltiwanger (1991) also find evidence supporting skill-augmenting technological change as the explanation for changes in the wage rate structure over the past three decades. Using data on plant characteristics and individual worker characteristics, they find that plant-size wage differentials have widened, that the manufacturing sector experienced a sharp increase in the educational attainments of workers, and that increases in work-force quality occurred disproportionately in large plants.

While technological progress is often cited as the key factor behind the shift in labour demand, much of the debate over the effect of technology on wage rates treats technology as a black box. Measures of technologies are rarely used to describe the nature of technological change. One exception is Krueger (1993), who uses a cross-section of workers and finds, after accounting for easily measurable worker characteristics such as education and age, that a substantial wage premium of 10 to 15 percent exists for those workers having computer skills.

[1] See Richardson (1995) for a summary of these arguments.

While Krueger's work is an improvement over previous efforts, simple measures of computer use do not capture the comprehensive way in which computers have been applied to the production of both goods and services. Computers are imbedded in machines that are used in different phases of the production process–design and engineering, fabrication and assembly, and inspection and communications. Assessing the importance of computer-driven technologies requires a more precise measure of the intensity with which they are used. Dunne and Schmitz (1995) make one of the few efforts to do so by examining wages for a cross-section of manufacturing establishments that use different computer-based advanced technologies. They find a substantial wage premium for production workers using these advanced technologies.

This study also uses a direct measure of technology use to investigate the existence of a technology premium for Canada. It does so by estimating a wage rate equation at the plant level for the manufacturing sector using matched data from the Survey of Manufacturing Technology[2] and the Census of Manufactures. Because the Canadian survey covers more industries than the U.S. survey,[3] the existence of a wage-technology relationship can for the first time be established for the manufacturing sector as a whole.

Finally, this study examines whether those plants using advanced technologies in 1989 differed from those not using technologies in 1989 much as the same two groups of plants differed in 1981. The paper finds that a higher wage premium for technology use existed between the technology and the non-technology users in 1989 than was the case for the same two groups of firms in 1980. This change is the result of an increase in technology use since 1981 within the technology using class and\or an increase in the premia associated with technology use–a twist in the relationship between wages and technology within the technology-using class. This demonstrates the origin of the labour-saving technological change and its relationship to the adoption of advanced technologies.

2. Data Sources

The data used in this paper are drawn from three sources—the 1989 Survey of Manufacturing Technology (SMT), the Census of Manufactures, and the 1993 Survey of Innovation and Advanced Technology.

The 1989 Canadian SMT asked establishments in the manufacturing sector to indicate their use, non-use or planned use of 22 separate advanced technologies. The Canadian survey covers technologies in areas such as design and engineering, fabrication and assembly, inspection and communications, automated material handling, manufacturing information systems, and integration and control.[4] The survey also collected data on several related characteristics of the

[2] Both Canada and the United States directly survey manufacturing plants to establish the use of particular advanced technologies.
[3] The U.S. survey is done for only five 2-digit industries–fabricated metal products, non-electrical machinery, electrical and electronic equipment, transportation equipment, and instruments and related products. The Canadian survey covers all of manufacturing.
[4] The Canadian survey covers 5 more technologies than the U.S. survey. The latter omits technologies in manufacturing information systems and integration and control.

establishment, including the availability of research and development facilities to the plant and whether it trained its employees, either within the plant or elsewhere. The survey, conducted by mail, was based on a sample of all establishments in the Canadian manufacturing sector.[5] The sample is stratified by size class, with a greater proportion of the larger plants being sampled than of smaller plants. Of the 4200 establishments in the sample 3952, or 94 percent, responded to the survey.

The responses to the SMT are linked to longitudinal panel data going back to 1980, taken from the Census of Manufactures.[6] This source yields information on a plant's employment, shipments, wages, and value added in manufacturing. In addition, data on the plant's owning enterprise—nationality, employment and age—are generated from special files maintained by the Micro-Economic Analysis Division. For this analysis, wage rates are calculated as the sum of wages paid to production workers divided by the sum of production workers employed.

Since this paper compares the wage structure of plants in 1989 and 1980, only those plants that continue throughout the decade are used in the regression analysis reported herein. The sample used includes neither the deaths nor the births that occurred between 1980 and 1989. After births and deaths are excluded from the linked file, the total number of observations used in the calculations is 3616.

Data from the 1993 Survey of Innovation and Advanced Technology are also used here to examine the effect of advanced technologies on skill requirements and training costs. This survey examined usage of the same 22 technologies discussed above, but also investigated a number of issues regarding the benefits relating to, effects of, and impediments to advanced technology use. A set of questions investigate the skill requirements associated with and the training costs resulting from advanced technology adoption. A total of 2877 firms were sampled for the technology section of the survey and the response rate was 88%.

3. Technology Use

The individual technologies used in this paper are listed by functional group in Table 1. The functional groups differ in terms of the degree to which they are directly involved in the production and assembly process or whether they serve to monitor it via diagnostics and quality control.

The technologies all emanate from the current technological revolution that is related to the computer, or more correctly, to micro-chip use. On the one hand, the relatively cheap processing power of micro chips has spawned the development of a host of labour-saving technologies. These technologies have permitted the replacement of costly labour with efficient, reliable, computer-controlled machinery. For example, robots provide an efficient and safe alternative to humans for repetitive jobs like spot welding or painting on the automobile assembly line. Automated guided vehicle systems replace delivery personnel.

[5] The U.S. survey covers only plants with more than 20 employees.

[6] Of the 3952 respondents, some 3642 or 92% are linked into the panel from the Survey of Manufactures.

As important as these labour-saving technologies might be, the new technological revolution has had equally important effects on enhancing labour, often management, in the tasks that they perform. The impact of information technologies has been felt in many different parts of the production process. They have allowed management to receive, digest, and analyze unprecedented amounts of information. They have permitted designers to ponder problems that they did not have time to consider previously, and to shorten the design phase of projects.

The integration of labour-saving and labour-enhancing technologies has created new manufacturing processes that are at the heart of what has been called "soft manufacturing". Bylinsky (1994) notes that "soft manufacturing" differs from traditional manufacturing in that software and computer networks are as important as production machines. These new technologies complement problem-solving skills in the workforce. The introduction of labour-enhancing technologies has been stimulated by the recognition that humans possess the invaluable kind of dexterity and judgment that has yet to be programmed into a robot. On the one hand, communications technologies permit skilled engineers to control a variety of processes. On the other hand, they allow real time ordering and the production of products on demand, tailored to specific needs. Communications and control technologies facilitate the rapid transmission of orders to the assembly process, the delivery of parts to the assembler, and the assembly of specialized products by a worker who is instructed by a computer as to the parts needed for the particular product that has just been ordered and the nature of the assembly required. Instead of replacing workers with robots, these technologies have enhanced human skills. In this environment, robots are relegated to repetitive tasks, while computer technologies aid workers to assemble custom-designed products with the aid of computer transmitted requests.

The effect of the information revolution has not been felt equally in all areas of production. The inspection and communications functional group has the highest adoption rate (Table 1). Some 79% of shipments in 1989 come from establishments using technologies from this group. The high adoption rate here is due mainly to the use of automatic control devices–programmable controllers and stand-alone computers used for control on the factory floor. The inspection and communications group is followed by design and engineering (52.1%), and manufacturing information systems (51.2%). Fabrication, the traditional heart of the production process, is only fourth with 46.7%. While the computer-based revolution is often described in terms of its effects on fabrication and assembly, its usage so far has been greatest in the area of the labour-enhancing technologies in inspection and communications as well as in design and engineering.

Data on changes in technology use over time are sparse, but available evidence suggests increases that are associated with the computer-based communications revolution have been large. Betcherman and associates (1994, p. 16) tracked 224 establishments from a wide range of sectors from 1985 to 1991 and found that the percentage of employees using computer-based technologies[7] in the sample increases over the period from 16% to 37%. More comprehensive data on changes in advanced technology use at the end of the eighties (Baldwin and Sabourin, 1995, pp. 55-60) show that technology use was increasing dramatically in the manufacturing

[7] Computer-based technologies in this survey consists of CAD, CAM, inspection, and automated material handling systems in manufacturing and word processing, personal computers, office networks, and other computer operations in the service sector.

Table 1. *Advanced Manufacturing Technologies by Functional Group*

Functional Group	Technology	Adoption Rate (Percent of Shipments)
Design and Engineering		**52.1**
	Computer-aided design and engineering (CAD/CAE)	49.0
	CAD output to control manufacturing machines (CAD/CAM)	20.1
	Digital representation of CAD output	12.7
Fabrication and Assembly		**46.7**
	Flexible manufacturing cells/systems (FMC/FMS)	20.6
	Numerically Controlled (NC) and Computer Numerically Controlled (CNC) Machines	29.6
	Materials Working Lasers	9.3
	Pick & Place Robots	14.9
	Other Robots	15.6
Automated Material Handling Systems		**18.4**
	Automated Storage/Retrieval Systems (AS/RS)	14.7
	Automated Guided Vehicle Systems (AGVS)	9.2
Inspection and Communications		**79.0**
	Automatic Inspection Equipment - Inputs	30.7
	Automatic Inspection Equipment - Final Products	34.9
	Local Area Network for Technical Data	40.8
	Local Area Network for Factory Use	36.7
	Inter-Company Computer Network (ICCN)	35.4
	Programmable Controllers	63.6
	Computers used for control in factories	49.9
Manufacturing Information Systems		**51.2**
	Materials Requirement Planning (MRP)	48.6
	Manufacturing Resource Planning (MRP II)	33.0
Integration and Control		**39.8**
	Computer Integrated Manufacturing (CIM)	21.1
	Supervisory Control & Data Acquisition (SCADA)	33.9
	Artificial Intelligence/Expert Systems (AI)	6.5

sector over the period 1989-93, despite the recession that took place at the same time. The largest changes occurred in design and engineering and in inspection and communications.

4. Technology Use and Skill Levels

New technologies may serve to reduce or to increase skill requirements. When technologies serve only to segment complex tasks into repetitive mundane chores, deskilling may occur. However, the new technologies, it is argued, facilitate complex activities that require combinations of judgment, dexterity, and experience (Bylinsky, 1994). The new forms of flexible production are seen to require a more highly skilled workforce (Matzner, Schettkat, and Wagner, 1990). Technology adoption increases the demand for workers with greater conceptual and problem-solving skills. Training, preparation, and learning are seen to be core elements in this new work environment (Keefe, 1991).

There are several reasons for believing that the increased use of advanced computer-based technology requires higher skill levels. First, the type of technologies that are being used most intensively are at the heart of the "soft-manufacturing" revolution. Communications and inspection technologies are used more frequently than other technologies; moreover they have been spreading more rapidly than other technologies (Baldwin and Sabourin, 1995). These technologies are essential to the new manufacturing processes, where software and computer networks have become just as important as machines. Using soft manufacturing techniques, firms tailor their products to individual buyers' needs, respond quickly to individualized orders and still achieve economies of size. Workers are called upon to concentrate on problem solving and improving the quality of products and services.

Even more direct evidence of a positive technology-skill relationship is provided by the 1993 Survey of Innovation and Advanced Technology. In this survey, managers of plants using technologies from each of four functional groups–design and engineering, fabrication and assembly, automated material handling systems, and inspection and communications–indicated that the introduction of advanced technologies in each of these areas increased their skill requirements more often than it reduced them (Table 2).[8] The percentage of plants experiencing an increase in skill requirements is four to five times larger than those experiencing a decrease.

Table 2. *Impact of Technology Adoption on Skill Requirements*

Technology	*Impact on skill requirements*		
	Increased	Unchanged	Reduced
	Percent of plants(shipment-weighted)		
Fabrication and Assembly	56	28	16
Automated Material Handling Systems	59	36	5
Design and Engineering	54	38	8
Inspection and Communications	47	47	6

Source: The Survey of Innovation and Advanced Technology (1993)

If technology is skill enhancing, producers would be expected to improve the skill levels of their workers by hiring more highly skilled workers and by providing more training. Training is likely to be chosen where firm-specific skills are particularly important since these types of skills can best be taught or acquired within the firm.

Data on the incidence of training in Canadian manufacturing establishments confirm the connection between technology use and the incidence of training. Baldwin, Gray, and Johnson (1995) use multivariate analysis to investigate the extent to which the incidence of training is related to the number of advanced technologies used. They find that technology is one of the most important determinants of the probability that a plant will train. The greater the number of advanced technologies in use, the greater is the complexity of the production process and the more likely is a plant to implement training programs. In addition, the plants that have R&D facilities and that are in more-innovative industries are also likely to do more training.

The training associated with the introduction of new technologies does not simply replace the skill enhancement programs associated with old technologies. Managers who had adopted

[8] The response rate to this question in the 1993 survey was 92%.

advanced technologies indicated that their training costs had generally increased (Table 3). Between two-thirds and three-quarters of technology-using plants reported that the adoption of advanced technologies led to an increase in their education costs.[9] A substantial portion indicated that their costs increased *moderately* or *significantly.* Thus, the increased skill requirements associated with advanced technologies have led to higher training expenditures for technology-using plants. Training has, in this sense, become more intense.

Table 3. *Impact of Technologically Advanced Equipment and Software on Education and Training Costs*

	Fabrication and Assembly	Automated Material Handling Systems	Design and Engineering	Inspection and Communications
	percent of plants (shipment-weighted)			
Increased significantly	23	15	20	20
Increased moderately	40	24	35	29
Increased marginally	14	16	24	19
No change	12	32	12	12
Decreased	1	0	0	0

Source: The Survey of Innovation and Advanced Technology (1993)

These three, separate, but related pieces of evidence support the argument that increased skill levels are related to advanced technology use at the plant level. Technology use has increased the demand for skills, led to more training, and increased the costs of training. Investments in human capital are needed to complement the investments that a firm makes in advanced technologies. To the extent that these investments require higher skilled workers that are in short supply, then a wage premium should exist for workers in plants that use advanced technologies. Moreover, since technology use has been increasing over time, the differences between those who are found to use technologies at the end of the period and non-technology users should have been widening over the period. The remaining sections examine the validity of these hypotheses.

5. A Summary of Wage-Rate Premia Associated with Technology Use

An overview of the relationship between the average wage rate and the intensity of technology use is provided in Table 4. The wage is calculated as total wages divided by total production workers in the plant. Intensity of technology use is measured as the number of technologies used (0, 1-2, 3-5, and 6+). Wage rates are classified by four groups of intensity of technology use (tech 1, tech 2, tech 3, and tech 4) and by four plant-size groups (Size 1, Size 2, Size 3, and Size 4) in order to compare the effect of technology use on wages to the well known plant-size premia (Mellow, 1982; Brown and Medoff, 1989; Groshen, 1991). The plant wage rate in each cell of Table 4 is indexed to the wage rate for plants in the smallest size class that uses no advanced technologies.

[9] The response rate to this question in the 1993 survey was 99%.

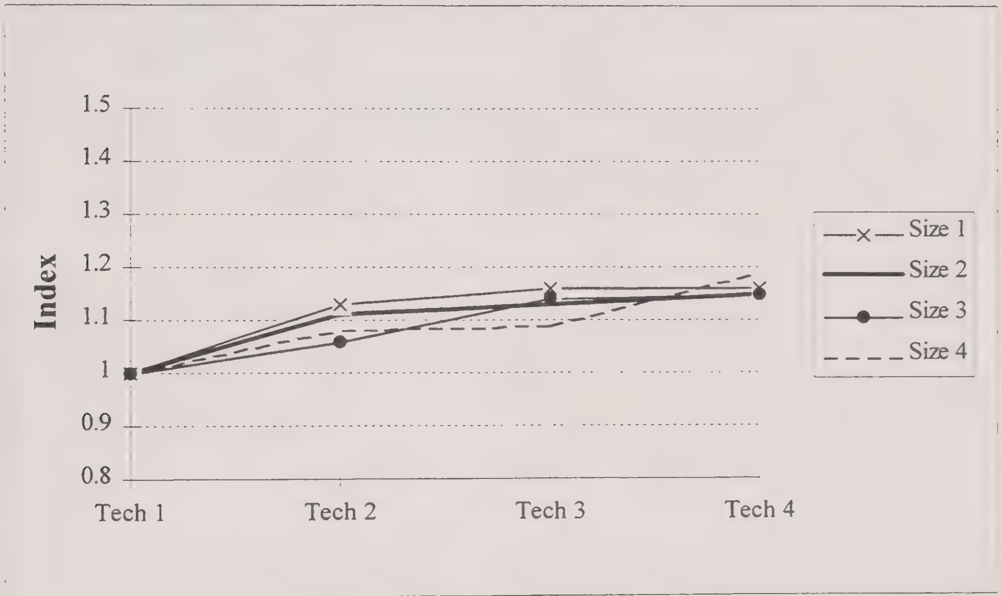
Table 4. *Average annual wage rates for production workers, 1989*

Plant employment	*Number of technologies in use, 1989* 0	*1 to 2*	*3 to 5*	*6 or more*
Less than 100	1.00	1.13	1.16	1.16
100 to 249	1.10	1.21	1.24	1.26
250 to 499	1.17	1.24	1.33	1.35
Greater than 499	1.42	1.54	1.55	1.69

Source: The 1989 Survey of Manufacturing Technology and the Census of Manufactures.

The data show a strong relationship between relative wage rates and the intensity of technology use. In the smallest plant size class (< 100 employees), wages increase by some 16 percent between the lowest (tech 1--0 technologies) and highest (tech 4--6 or more technologies) technology-using classes. This relationship holds for all size classes. Figure 1 plots the wage by size class of each of the technology groups relative to the wages of plants using no technologies, within the size class, i.e. wages of plants using no advanced technologies (tech 1) are set equal to one for each size class. The wage premia for the highest technology-using group (tech 4) are remarkably similar for all size classes. The premium for the group using 6 or more technologies is 16, 15, 15 and 19 per cent for the first, second, third, and fourth size classes, respectively.

Figure 1. Relative Wages of Size Classes by Technology Usage

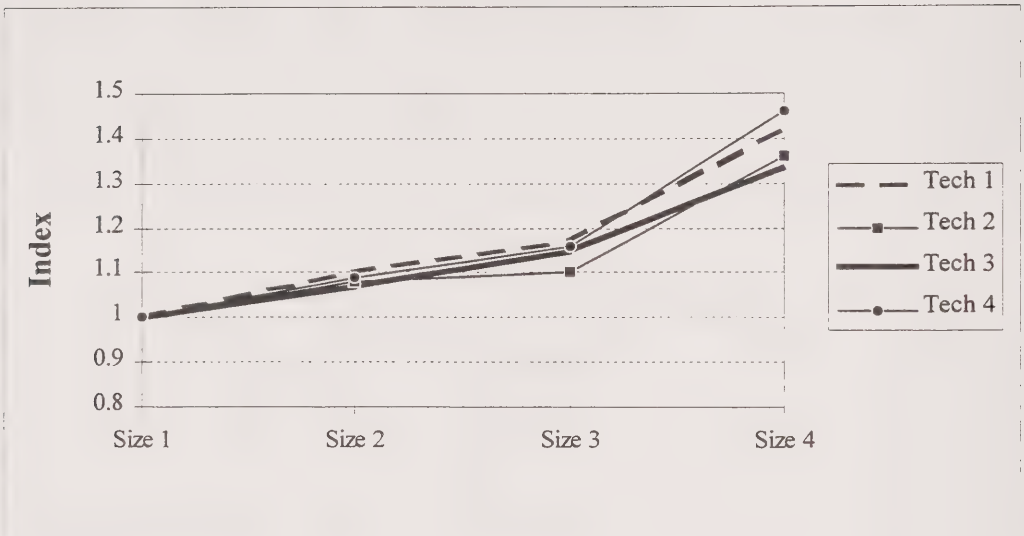


The importance of advanced technologies and skill upgrading is much greater for large than small plants. Large plants are more likely to use advanced technologies. They are more likely to combine technologies from different functional categories and to operate integrated factories. They are more likely to use many advanced technologies and to use the more sophisticated technologies from each group (see Baldwin and Sabourin, 1995). Therefore, when they adopt advanced technologies, they more frequently find that their skill requirements increase. They more frequently introduce training programs to develop the skills that they require. They are also

more likely to find that their training costs increase significantly after adoption. It is likely then, that the skill premium for workers that is associated with technology use will be related to the size of the plant.

These hypotheses are confirmed in Figure 2, where the relative wage across each size class is plotted for each technology group (tech 1, tech 2, tech 3, and tech 4). For each technology group, the relative wage is indexed to that of the smallest size class. The relative wage increases across size classes for each technology group. Moreover, the wage-size relationships are similar across technology groups. Within the four technology groups, the largest size class has a premium of 42, 36, 34 and 46 per cent, respectively.

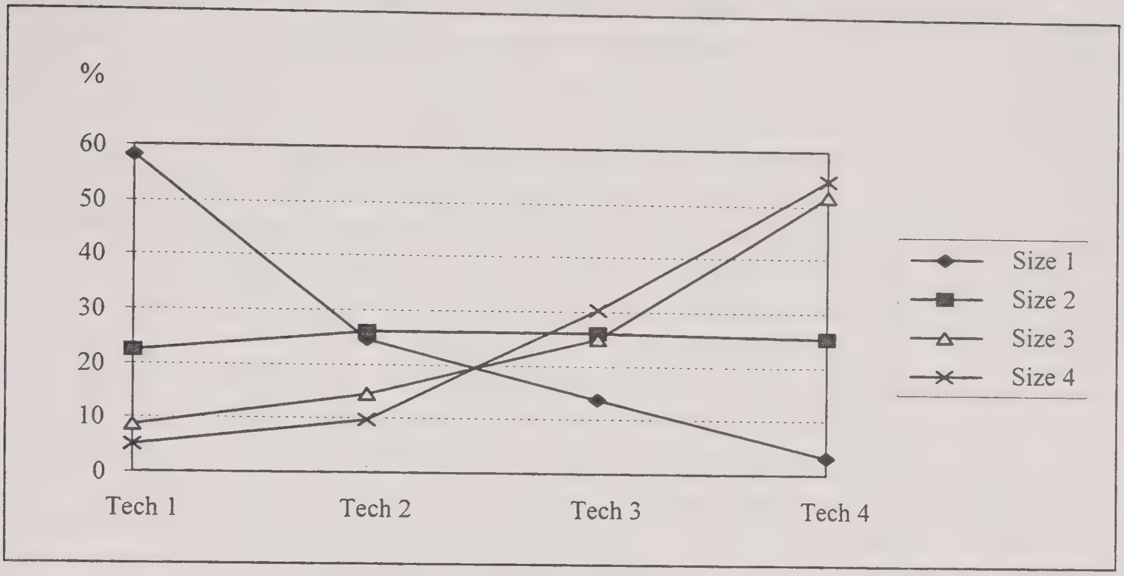
Figure 2. Relative Wages of Technology Groups by Size Class



It is also the case that the smallest plants use fewer multiple technologies. The share of plants in each size class that falls into the different technology groups is graphed in Figure 3. In the smallest size class, almost 60% use no advanced technologies, less than 10% use 6 or more technologies. By way of contrast, less than 10% use no advanced technologies and almost 60% use 6 or more advanced technologies in the largest size class.

The premia reported in Table 4, and Figures 1 and 2 that is received by workers in plants using greater numbers of advanced technologies varies depending on the type of technology being used: Technologies can be classified by functional group–design and engineering, fabrication and assembly, automated material handling, inspection and communications, automated control devices, manufacturing information systems, and integration and control. The relative wage rate of technology users–the wage rate of users divided by the wage rate of non-users–is presented in Table 5 by functional group. Users are defined as plants that adopt any one of the technologies within the functional group, non-users are those not employing any of the technologies within that functional group (see Table 1). In addition to the six main functional groups, automatic control devices, a subset of inspection and communications, is included.

Figure 3. Percentage Users by Size Class



In 1989, the wage rate of technology-using plants is higher than non-users in all functional groups. The largest advantage occurs for inspection and communications as well as integration and control. These plants pay 28% and 27% more than plants that do not use any inspection and communications or integration and control technologies. The smallest difference occurs in manufacturing information systems.

Table 5. *Relative Wage Rates by Functional Group, 1981 and 1989 (weighted)*

Technology Group	Group	Adoption Rate 1989 (% of shipments)	Relative wage rate, users/nonusers 1989	Relative wage rate, users/nonusers 1981
Design and Engineering	1	52.1	1.22	1.16
Fabrication and Assembly	2	46.7	1.14	1.12
Automated Material Handling Systems	3	18.4	1.17	1.13
Inspection and Communications	4	79.0	1.28	1.22
Automatic Control Devices	4a	67.1	1.28	1.21
Manufacturing Information Systems	5	51.2	1.11	1.08
Integration and Control	6	39.8	1.27	1.19
Combination 1	C1	14.9	1.26	1.22
Combination 2	C2	22.8	1.15	1.12
Combination 3	C3	23.3	1.26	1.20

Note: The 22 separate advanced manufacturing technologies in the SMT have been divided into 7 functional groups, based in their use in the production process. Technology use in a given functional group is defined to occur when the plant uses at least one of the technologies in that group. Wage rates are calculated relative to non-users of that *particular* functional group of technologies.
Source: The 1989 Survey of Manufacturing Technology and the Census of Manufactures.

The relative wage rates in 1981 for the same two groups of plants–those using and those not using advanced technologies as of 1989–are also included in Table 5. The relative wages of the 1989 technology-using group are higher everywhere in 1989 than in 1981. The changes in the relative wage rates between 1981 and 1989 reflect two factors–changes in the effect of technology use on wages and changes (mainly increases) in the intensity of technology use. On the one hand, the increase in relative wages reflects improvements in the wages of the plants that

used technology both at the beginning and end of the period relative to those not using advanced technologies in either year. On the other hand, part of the increase in relative wages reflects the general increase in technology use that has been occurring. Some plants who were non-users at the beginning of the period have become users over the time period and have improved their wages relative to those that did not use advanced technologies in either 1981 or 1989.[10] Similarly, plants that were advanced technology users at the beginning of the period generally increased their intensity of use over the period.[11] Thus, the increase in the relative wages of 1989 technology users between 1981 and 1989 occurs because some technology-using plants have become more intensive users of each technology and because the effect of using advanced technologies on wage rates has intensified.

In addition to the disparity between wage rates paid by users and non-users, there is a considerable variation in wage rates within the set of technology-using plants. The highest relative wages are paid, both at the beginning and the end of the period, by those establishments using the labour-enhancing technologies (inspection and communications, integration and control). Relative wages for the labour-saving technologies in fabrication and assembly are among the lowest in both periods. Furthermore, the disparity between the labour-enhancing and labour-saving technologies grew over the 1980s. The wage-rate premia have gone up relatively more for those technologies that received the highest premia in 1981. The two labour-saving categories have among the lowest premiums in 1981 (fabrication and assembly, automated material handling systems) and experience the smallest rate of increase; the one with the largest initial premium (inspection and communications, a labour-enhancing technology) experiences the largest rate of increase.

The growth in the relative wage rate of technology users is plotted in Figure 4 for each technology grouping. The growth rates for both the unweighted sample, which contains a disproportionate number of large plants, and for the population (weighted results) are presented. Differences between the weighted and the unweighted results reveal the extent to which large and small plants perform differently. The weighted results have the largest growth rates in the integration and control category, followed closely by automatic control devices and inspection and communications. In the unweighted sample, these three categories also lead the list. In the weighted case, plants that use fabrication and assembly technologies have one of the lowest growth rates. The soft manufacturing revolution has associated the largest wage gains with labour-enhancing technologies.

The 22 separate technologies are often combined within a plant, since multi-technology use is frequent. However, multiple technology use does not necessarily imply that factories are integrated. Integrated factories are those using technologies in each of several different production divisions–such as design and engineering, fabrication and assembly, as well as inspection and communications. To investigate the effect of technology integration on wages, three combined categories of cross-functional group use (combination 1, combination 2, and

[10] It is likely that establishments that were non-users in 1989 were non-users in 1981; however, users in 1989 may not necessarily have been users in 1981.

[11] Baldwin and Sabourin (1995) find that intensity of use increased more between 1989 and 1993 than did incidence of use, that is, the percentage of plants using multiple technologies increased at a faster rate than the percentage of plants using any advanced technology.

combination 3) are created that measure integrated technology use. The first comprehensive category (combination 1) is defined as the use of one advanced technology from each of the five groups–design and engineering, fabrication and assembly, inspection and communications, manufacturing information systems, and integration and control.[12] This mix of technologies represents *comprehensive technology use in a fully integrated factory*. The second set (combination 2) is similar to the first, but involves a somewhat more restricted concept of comprehensive use in that it excludes integration and control technologies. It represents *comprehensive technology use that is not fully integrated*. The third combined category (combination 3) represents the use of *integrated technologies focused on the factory floor*. It combines technology use from fabrication and assembly, automatic control devices (programmable controllers and in-factory computers for control) from the inspection and communications group and technologies from the integration and control group.

The combined categories are characterized by some of the highest relative wage rates in 1989 (Table 5). In addition, the growth in the relative wage rates over the decade for plants using the technology combinations is generally quite high (Figure 4)–at least for the two comprehensive combinations that involve an element of integration and control. Advanced fabrication and assembly technologies do better when combined with other technologies–especially integration and control technologies. It is, therefore, evident that multiple technology use that involves integrating technologies across groups frequently has particular advantages and that these advantages grew over the 1980s.

These data suggest that an advantage has developed for multiple technology users. In order to chart the development of this advantage in the 1980s, the relative wage differential of multiple technology users and non-users of any advanced technology is tracked between 1981 and 1989 (Figure 5). Three different classes of multiple use are employed–1) plants using only 1 to 2 technologies in 1989, 2) those using 3 to 5 technologies and 3) those using 6 or more technologies. The wage rates for plants that fell in any of these multiple technology categories increase over the decade relative to those plants using no technologies; however, the increase is largest for those using 6 or more technologies. As a result, the wage rate differential within the group using technology widens over the decade.[13]

In conclusion, technology use is associated with a wage premium. The premium is highest in those plants using the most technologies. Finally, plants using technologies with a relatively high wage premium in the beginning of the 1980s were the most likely to have had the largest increase in this premium over the decade.

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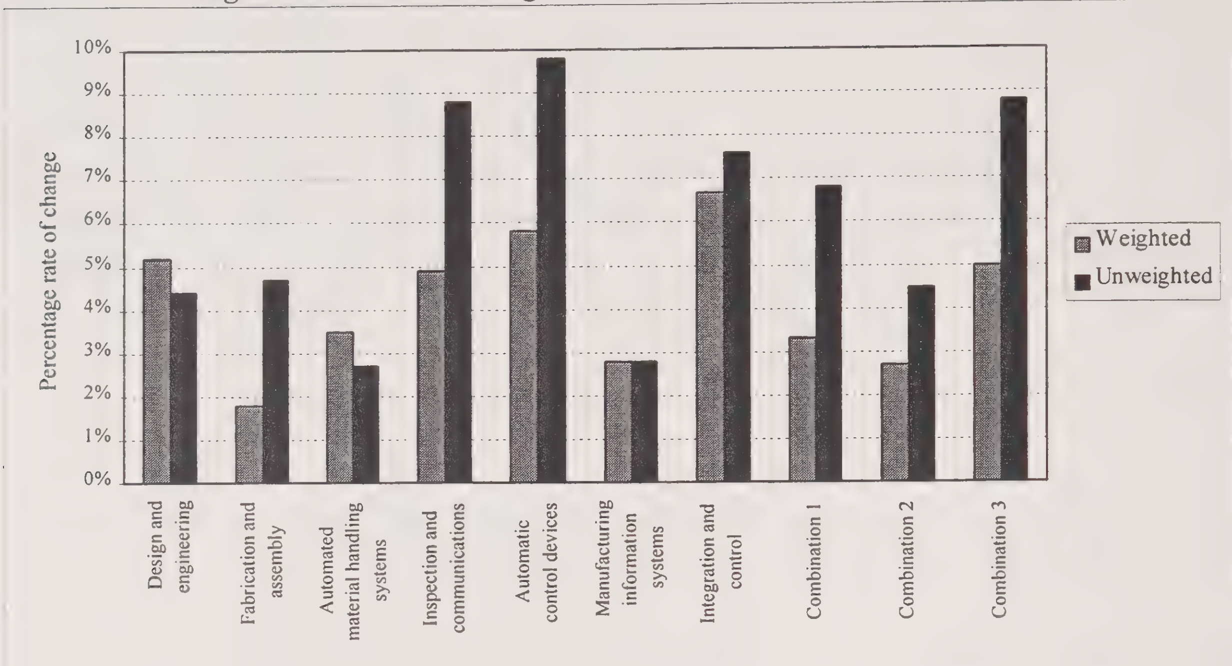
[12] Automated material handling systems is excluded from this definition since the application of these technologies is relatively limited. It has the lowest usage rate of all the groups and, when used, is concentrated in a subset of manufacturing industries.

[13] Figure 5 shows that those using multiple technologies at the end of the decade also had a wage advantage at the beginning of the decade and that they increased that advantage over the period. It does not show that those plants paying the highest wages at the beginning of the period increased their use of technologies the most.

Figure 4. Rates of Change in Relative Wage Rates in the 1980s



(note: growth rates significantly greater than zero at the 5% level, using a one-tailed-test)

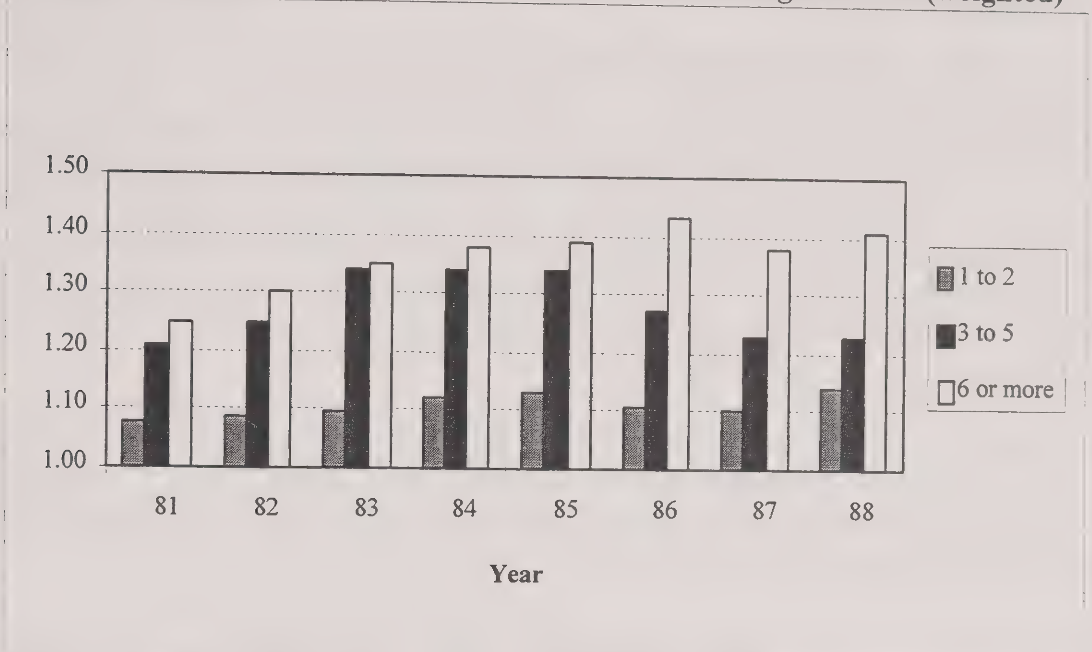
These changes may have been closely bound up with other structural changes that were occurring. Plant-size premia could have been changing and thus the relationship between wages and technology use may simply reflect changes in size premia–because technology use is so closely related to plant size. Or it may be related to changes in the patterns of foreign ownership or capital intensity, both of which are correlated with technology use. In the remainder of the paper, multivariate analysis is used to examine whether the technology premia and changes in the premia that are associated with technology use can still be found once a number of other factors that are associated with plant wage rates are taken into account.

6. Model and Variables

a) The Model

Wages are hypothesized to be a function of plant size, the capital-labour ratio, and a number of plant characteristics that are both direct and indirect measures of the technological sophistication of the plant. This formulation can come from the view that wages are constant across plants except for variations in the quality of workers contained in each plant and these are the characteristics which lead plants to use relatively higher skilled workers and, therefore, should be related to wages paid. Or, the formulation can have as its base a neoclassical demand for labour function–using the assumption that workers are paid their marginal revenue product and the assumption of a particular form of a production function. For example, if the production function is assumed to be Cobb-Douglas, then

Figure 5. Relative Wage Rates by Number of Technologies in Use (weighted)



Note: For each of the years 1981 to 1988, wage rates of users are calculated relative to wage rates of non-users of technology based on use patterns in 1989.
Source: The 1989 Survey of Manufacturing Technology and the Census of Manufactures.

1) $Q = AK^{\alpha} L^{\beta}$

Then the marginal productivity conditions yield,

2) $\ln W = M + (\alpha+\beta-1) \ln L + \alpha \ln(K/L)$

where:

$\ln W$= log of the average annual production worker wage;
$\ln L$= log of plant employment (enterprise employment);
$\ln K/L$= log of the capital-labour ratio.
M = function of A, price of the product and β

Equation #2 normally presumes that labour is homogeneous. Yet, there are substantial skill differentials across plants. Some of these relate to plant size (Brown, Hamilton and Medoff, 1989, pp. 32-36). Others are hypothesized to be a function of the capital intensity of the plant, the types of technologies used, the innovativeness of a firm, and other characteristics that are related to the degree of sophistication of the firm. These characteristics, which are presumed to affect the quality of labour, are subsumed within a vector C.

Then, the wage rate equation is,

$$3)\qquad \ln W = \gamma C + (\alpha+\beta-1)\ln L + \alpha \ln(K/L)$$

Two types of regressions of this form are reported here. The first employs unweighted estimates using the 3642 plant sample. This sample contains a greater proportion of large plants than exist in the population. The second set of regression results are establishment-weighted. Weighting by establishments produces results that are representative of the average manufacturing plant. As most plants are small, the second set of results is representative primarily of small establishments. Differences in the two sets of results reveal the extent to which the relationship between wages and technology differs between large and small plants.

Two estimating techniques were employed. The first is ordinary least squares. However, the technology, labour, and capital-labour ratios are likely to be endogenous. The second technique uses the rank of each of these variables as an instrument to perform two stage least squares regression analysis. Essentially the same results are produced by each technique.

b) The Variables

Wage Rates

The log of the wage rate paid to production workers is used as the dependent variable in the regressions. The average annual wage is calculated as the total wage bill for production workers divided by the total number of production workers.[14] This is equivalent to the employment-weighted average wage per production worker. A two-year average (over 1988-89 for 1989 and 1980-81 for 1981) is used in order to smooth out random movements.

Plant and Enterprise Size

Plant size is represented by plant employment–the average total plant employment over a two year period (for 1981 employment, the average employment over the 1980-81 period is used; for 1989 employment, the average employment over 1988-89 is used). Plant employment includes both production workers and salaried employees.

Enterprise size–the total number of production and non-production workers–is also included. In order to separate the size of the enterprise from that of the plant, enterprise employment is calculated as residual employment–i. e., total enterprise employment outside the plant.[15]

[14] See Baldwin and Rafiquzzaman (1996) for a treatment that examines the effect of technology use on the differences between non-production and production worker wages.

[15] Enterprise employment is defined as the total employment of all plants in manufacturing, mining and logging under common control.

Capital-Labour Ratio

The capital-labour ratio is proxied by profits in manufacturing divided by production workers, again calculated as the average over the relevant two-year period. The ratio is calculated as total activity value-added minus the wage bill of production workers and salaried employees divided by the number of production workers.

Since profits are just the rate of return earned on the capital invested ($\rho_i * K_i$), then profits divided by labour is just $\rho_i * K/L_i$. As long as competition equates the risk-adjusted return across businesses (ρ), the profits/ labour variable is just the capital-labour ratio multiplied by a constant.

Use of profits divided by labour will not perfectly reflect differences in the capital-labour ratio if the rate of return is not equated across businesses. It may be that technology users earn a higher rate of return. If so, the profit/labour ratio will be correlated with technology use and will partially capture the effect of technology. One way to partially correct for this is to use the ratio of profits to wages to capture the capital-labour ratio. Profits divided by wages is just the capital-labour ratio multiplied by the rate of return divided by the wage rate. If both the rate of return and the wage rate at the plant level are positive functions of technology use, this variable may be less related to technology use than is profits over labour input. In this case, profits over wages will better capture just the effect of capital-labour intensity. While the profits to labour variable is used throughout the study, the result of using profits to wages is also reported to show the sensitivity of the results to the proxy used.

Technology Use

There are two reasons for including technology variables. On the one hand, technology captures aspects of capital intensity that the dollar-value measure of capital does not. While the normal practice is to encapsulate all information on capital into one aggregate measure using dollars as the common numeraire, these measures may not capture differences in the efficiency of machines. If new generations of machines cost about the same as their predecessors but are much superior, then plants with more recently purchased machinery could produce far more with the same dollar amount of capital. Specification of the capital stock in more detail, using information on the types of machines in use, potentially corrects for these shortcomings of dollar measures of capital.

Technology use is also a proxy for the skill levels of employees. Technology use is associated with more highly skilled workers. Others (Mincer, 1992) have stressed that physical capital and skilled human capital are complements. Baldwin and Johnson (1995) demonstrate that the emphasis that a firm places on training is a function of the degree to which it is technologically innovative. Baldwin, Gray and Johnson (1995) show that plants are more likely to train their employees when they use advanced manufacturing technologies. The use of advanced manufacturing technologies then also captures firm-specific skills embedded in the workforce. These skills might be captured by traditional education variables should they be available; however, in light of the pervasiveness of in-firm training programs associated with advanced technologies, the skills required here probably have dimensions that are different from the years-of-schooling variable that is often used.

Technologies can be measured here in two separate ways–first, as the number of technologies used and, second, by the type of technologies used. The number of technologies measures intensity of use across all functional categories.[16] Plants that use a large number of technologies are more likely to be sophisticated. Alternately, technology use is measured as the number of technologies within a functional group. Here, the 22 separate advanced technologies for which the SMT collected data are grouped into 6 functional groups, according to their location of application in the production process. These functional groups are: design and engineering; fabrication and assembly; automated material handling systems; inspection and communications; manufacturing information systems; and integration and control technologies. Six binary variables, each of which captures the use of *any* technology within a particular functional group, are then used in the regression.

Other Plant Characteristics

A number of additional characteristics are included to capture other factors that have been found to be related to wage rates–age of plant, ownership by a firm that possesses more than one plant (Davis and Haltiwanger, 1991). Each of these characteristics is hypothesized to affect the quality of a plant's workforce or the efficiency parameter (A) of the production function in equation #1. Each of these variables is listed below:

Age

Older plants are those that have managed to survive. On average, they will have built up accumulated knowledge that allows them to apply the same machines in a more sophisticated manner or to have developed a more highly-skilled labour force. A binary variable serves to classify plants on the basis of their age. It takes a value of one for those plants that were established before 1970, and value of zero for those that were younger.[17]

Diversification

Making advanced technologies work requires a set of sophisticated organizational skills. These are more likely to be present in a multi-establishment enterprise where a wider range of experiences is mastered by the firm's production engineering team. Therefore, firms are hypothesized to possess a more sophisticated skill set when they are diversified. Diversification is captured here as a multi-plant binary variable, which equals one if the plant is owned by a firm that operates more than one plant in the same 4-digit SIC industry where the plant is located, and zero otherwise.

Innovation

Plants in some industries are likely to require more sophisticated skills because these industries engage in more complex technological and innovative activities. In order to capture this effect, a binary variable classifying industries as either more- or less-innovative is included in the

[16] Alternately, four categories were used–zero, one to two, three to five, and six or more technologies. Since no serious nonlinearities were present, the categories were combined into one variable–number of technologies.
[17] The sample contains a relatively small number of plants that were born in the 1980s.

regression. The classification is derived from Robson et al., (1988). Their study of the differences in the innovative tendencies of 2-digit industries classifies industries into three basic groups. The first two groups, defined here as the innovative industries, produce the majority of innovations. The more innovative industries consist of electrical and electronic products, chemicals and chemical products, machinery, refined petroleum and coal, transportation equipment, rubber products, non-metallic mineral products, plastics, fabricated metals, and primary metals. The less innovative group are made up of the textiles, paper, wood, clothing, leather, beverages, food, furniture and fixtures, and printing and publishing industries.

Foreign Control

The nationality of a plant is used to capture other competencies that are hypothesized to be positively associated with a firm's ability to exploit the benefits of advanced technologies. Multinationals are the vehicle through which hard-to-transfer scientific knowledge is moved from one country to another (Caves, 1982). This is partially the result of an inherent advantage associated with information that is uniquely held by these types of firms. To capture the advantages of foreign-owned plants, a binary variable is included that equals one if a manufacturing plant is foreign-controlled, and zero otherwise.

7. Results

a) 1989 Wage Rates

The regression results are presented in Table 6. The first column is the base case–the unweighted ordinary least squares (OLS) version with plant size, the capital-labour ratio, number of technologies and plant characteristics. Column 2 adds enterprise size. Column 3 is the establishment weighted version of column 1. Column 4 is the instrumental variables version of column 1–with number of technologies, plant size, the capital-labour ratio and the wage rate all assumed to be endogenous.

The results confirm other findings that the wage rate depends both on the size of plant (Mellow, 1982, Brown and Medoff, 1989) and the ratio of capital to labour (Davis and Haltiwanger, 1991). However, even after both the size of the plant and the capital-labour ratio are taken into account, the number of technologies used is positively related to the wage rate. The presence of advanced technology, both as a direct measure of the effectiveness of a plant's capital and as a measure of the presence of special skills, is associated with a positive wage premium for production workers.[18]

The hypotheses about the effects of other plant characteristics are also confirmed. The wage premium in plants that are older is 2.4%; in plants that are more diversified, it is 14.7%; in plants that are foreign-controlled, it is 5.9%, and in plants that are located in more-innovative industries, it is 10.3%. With the exception of age, all coefficients are highly significant.

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[18] When profits divided by wages is used as the proxy for the capital-labour ratio, the effect of technology increases, as was expected.

Table 6. *Wage Rates and Technology Use: 1989*

Variable	Ordinary Least Squares						Instrumental Variables	
	Unweighted		Unweighted		Weighted		Unweighted	
Intercept	9.60	***	9.64	***	9.78	***	9.37	***
Age	0.024	*	0.020		0.045	***	0.025	*
Foreign-owned	0.059	***	0.025	**	0.084	***	0.035	***
Innovative industry	0.103	***	0.099	***	0.072	***	0.096	***
Multi-plant enterprise	0.147	***	0.035	**	0.109	***	0.136	***
Technology Use	0.012	***	0.011	***	0.012	***	0.013	***
Capital-labour ratio	0.018	***	0.017	***	0.004	***	0.048	***
Plant size	0.041	***	0.028	***	0.028	***	0.031	***
Enterprise size	---	---	0.024	***	---	---	---	---
R-squared adj.	0.26		0.290		0.155		0.284	
F	182.7	***	184.5	***	94.6	***	204.5	***

** significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level*

When enterprise employment is added to the regression (column 2, Table 6), the effect of both foreign-ownership and diversification are diminished. This is caused by the fact that large enterprises tend to be foreign-owned and multi-plant (Baldwin and Diverty, 1995). The inclusion of enterprise employment as a size variable partially captures these effects.

The establishment-weighted results (column 3, Table 6) for the effect of technology on wages are very similar to the unweighted results. Thus the effect of technology on wages is much the same for both small and large plants. The coefficients on age and ownership increase in the weighted version, thus demonstrating that these characteristics have a greater effect on wages in small plants.

Similarly, there is little difference between the OLS and the instrumental variable results, with the exception of the coefficient on the capital-labour ratio. In light of this result, only OLS results are reported in the remainder of the paper.

In a U.S. study, Davis and Haltiwanger (1991) find similar results for many of these variables. Higher wages were paid at larger, older, more capital intensive plants, and at plants that were part of a multi-unit firm. Several explanations are offered to explain the size premia.[19] The first is that large plants use higher quality workers (and hence pay higher wages) because of greater capital intensity. Another explanation centers on monitoring costs–larger plants employ higher-quality workers in order to reduce monitoring costs per unit of labour services. Alternately, larger plants may use technologies that require greater amounts of teamwork and standardization than those used by smaller plants and, therefore, require a higher quality work force.

Dunne and Schmitz (1995) also report a size/wage premia. Similarly, they find that the number of technologies and a multi-plant indicator are both important determinants of a plant's wage rate. Since they did not include the dollar value of capital as a separate variable in their model, the effect of technology in their formulation may be a proxy for this traditional measure of

[19] Groshen (1991) also reports a size premium after allowing for measurable differences in worker characteristics. Morissette (1993) reports the same findings for Canada.

capital intensity. Our results show that, even after controlling for the dollar value of capital, technology has an important influence on wage rates.

These results indicate that wages are an increasing function of the number of technologies used. In order to investigate which functional areas lead to the highest wages when other plant characteristics are considered, wage rates are regressed on measures of technology intensity for each of six functional groups and the same set of plant characteristics. Foreign-ownership, multiple-plant operation, and innovativeness again have positive effects on the wage rate paid to production workers, as do the capital-labour ratio and plant size. Since the coefficients attached to each of these variables are very similar to those reported previously, only the coefficients attached to intensity of technology use within each of the functional categories are reported in Table 7. Both unweighted (essentially large plant) and weighted (population) results are presented.

Table 7. *Wage rates and type of technology in use, 1989*

Type of technology in use	Unweighted		Weighted	
	coefficient	Significance	coefficient	Significance
Design and engineering	0.027	**	0.058	***
Fabrication and assembly	-0.008		-0.028	**
Automated material handling systems	0.035	*	0.026	
Inspection and communications	0.088	***	0.055	***
Manufacturing information systems	-0.051	***	-0.065	***
Integration and control	0.055	***	0.106	***
R-squared adj.	0.273		0.174	

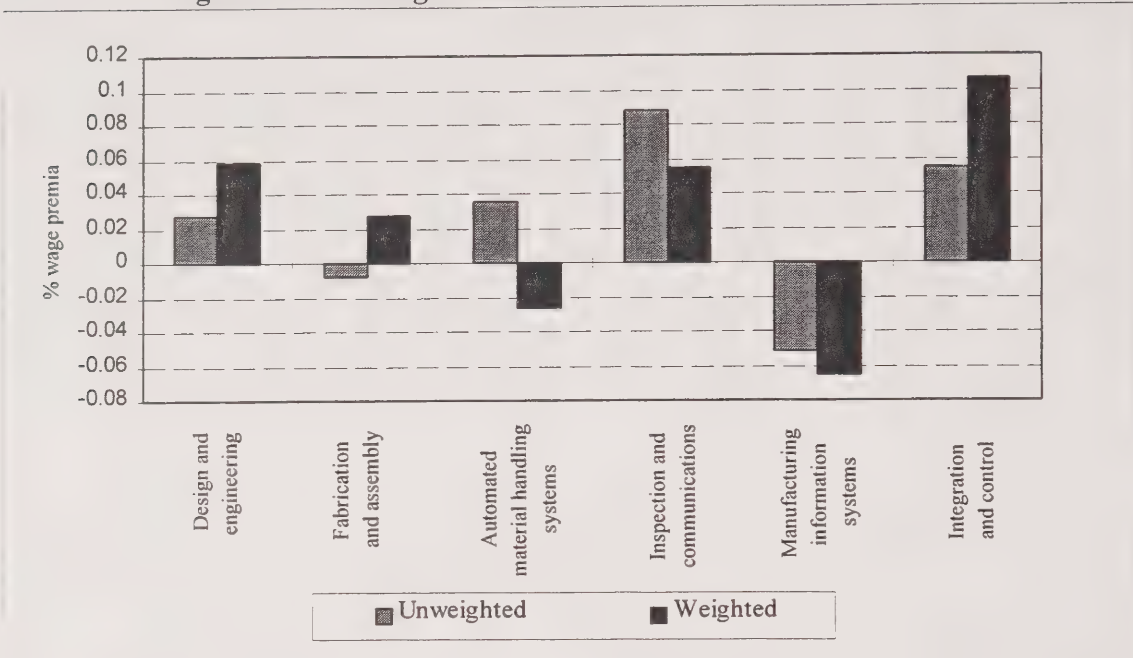
** significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level*

In the large-plants results, the use of technologies from inspection and communications, integration and control, design and engineering and automated material handling systems have positive and significant effects on the wage rate of production workers. For large plants, the largest positive effects are associated with the two labour-enhancing categories–inspection and communications, and integration and control. The smallest positive effect occurs for design and engineering technologies. Wages are no higher in plants using fabrication and assembly technologies than in those not using these technologies.[20] The effects for each of these technology groups (see Figure 6), which take into account the impact of other plant characteristics, are qualitatively the same as those reported in Table 5.

In the weighted results, the effect of design and engineering, fabrication and assembly, as well as integration and control are all higher; the effect of inspection and communications is slightly lower, though it still is just as high as in the other functional groups. Fabrication and assembly technologies have a negative effect in the population as a whole on wage rates once the effect of using each of the other technologies on wages has been controlled for.

[20] Inclusion of enterprise size has no significant effect on the coefficients attached to technology use in each of the functional categories.

Figure 6. The Wage Premia from the Multivariate Analysis



8. *Comparison of 1989 and 1981 Technology Effects*

a) Methodology

Of particular interest is the extent to which changes in the wage rate structure over time can be associated with technology use. In order to investigate this, a regression of the form employed in the previous section is used and observations on wage rates and plant characteristics in 1981 and 1989 are pooled.[21] The regression takes the form:

$$4)\ \ln W_{it} = F(Y_{it}) = \gamma_t C_{it} + (\alpha+\beta-1)_t \ln L_{it} + \alpha_t \ln(K/L)_{it}$$

where Y_i is the vector $(C_i, L_i, K/L_i)$, $i = 1,2,3...7232$ and $t=1,2$.

The pooled regression that is reported in Table 7 has the form

$$5)\ \ln W_{it} = F(Y_{it}) + \delta_i F(Y_{it})^* D_1$$

where D_1 takes a value of 1 if the observation is for 1989 and 0 if for 1981. If the coefficient δ_i is different from zero, then this characteristic affects the wage structure differently in 1989 than

[21] To control for inflation, 1989 wages are deflated to 1981 levels using the ratio of average of the logarithm of annual wage rates in 1989 divided by the average of the logarithm of wages for 1981. Similarly, the ratio of profits to nominal capital stock in 1989 to 1981 was used to deflate the 1989 individual plant values of profits to labour in 1989. A second measure of "real capital" was also employed. This measure was generated by deflating profits by the output inflation at the industry level. The findings are essentially the same as those for the first measure of real capital, and thus, are not presented here.

1981. All variables except for technology are measured in both 1989 and 1981. Technology use can only be measured in 1989 since this is the year of the technology survey. The coefficient attached to the technology variable in equation #4 measures how the wage structure has changed between 1981 and 1989 for those plants using technologies in 1989. As already indicated, it captures the two causes of wage polarization–twists in the wage structure for different technology classes and/or changes in the intensity of technology use.

b) Results

The results of the pooled regressions are reported in Table 8. Only the weighted results are reported here. The coefficients on the interactive terms involving a plant characteristic and the year binary variable represent the differential effect of the plant characteristic on the wage structure in 1989 compared to 1981. Only those characteristics that had a significant interaction term (a different effect in 1989) are included. Foreign-ownership, being in an innovative environment, age, and diversification have the same effect on the wage rate in the two periods, that is, their interaction terms were not significant.

If the wage-rate equation is appropriately identified and estimated so as to produce coefficients that represent the inverse demand function, these interactive terms represent demand shifts alone. However, if the wage rate equation primarily reflects the manner in which quality differentials affect the average wage, the coefficients represent both demand and supply effects. The estimating equation for the wage rate is a form of hedonic price index whose coefficients are jointly determined by both bid and offer functions (see Bartik, 1987). The interactive shift coefficients attached to a plant characteristic, like size, may increase either because the demand for a particular quality of labour associated with plants of that characteristic has increased (i.e. larger firms require higher skilled workers), or because the supply of this type of labour has become relatively more expensive.[22]

The first column of Table 8 uses just the number of advanced technologies to represent technological sophistication. The second column divides technology use into labour-enhancing technologies (inspection, communications, integration and control) and all other technologies (design, fabrication and assembly, manufacturing information systems). Both columns 1 and 2

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[22] Consider a world with two types of labour, skilled (S) and unskilled (U) where plants face a perfectly elastic supply of each type labour at wages W_s and W_u, and $W_s > W_u$. The average wage rate $(\overline{w})$ in a plant where α is the proportion of workers who are skilled and α depends upon characteristic X is

$$\overline{w} = (1 - \alpha)\, W_u + \alpha\, W_s, \text{ where } \alpha = f(X)$$

setting $W_u = 1$ as numeraire

$$\hat{w} = 1 + \alpha\,(W_r - 1) \text{ where } W_r = W_s / W_u \text{ and } \hat{w} = \overline{w} / W_u$$

$$\text{Then } \delta\, \hat{w} / \delta t = \frac{\delta \alpha}{\delta t} \cdot (W_r - 1) + \alpha\, \delta\, W_r/\delta t$$

The estimated coefficients then capture the effect of a shift in the effect of X (i.e., plant size) on the proportion of workers who are skilled and an increase in the relative wage of skilled versus unskilled workers.

test whether technology use is associated with a change in the wage-rate structure that is independent of the size and capital intensity of the plant since technology use is interacted only with a year binary variable representing the second period. The third column investigates the extent to which technology use interacts with both the capital-labour and the size variable.

In the first equation (column 1, Table 8), the second period interaction term on the number of technologies is positive and significant at the 10% level. This suggests that the slope of the relationship between numbers of technologies used and wages increased over the decade or that firms were using more technologies in 1989 than they were in 1981. The other two interaction terms that have a significantly different impact in 1989 than 1981 are labour (size of plant) and the ratio of capital to labour. The coefficient on the year interaction term and the capital-labour ratio is negative; the coefficient on the year interaction term and size is positive. If the coefficient attached to the capital-labour ratio is interpreted to represent the marginal product of capital (α) in the Cobb-Douglas production function, the productivity of capital has decreased over the period. Similarly, since the coefficient attached to size (labour) in equation #4 represents the scale coefficient ($\alpha+\beta-1$) and α has decreased, the increase in $\alpha+\beta-1$ can be interpreted to mean that there has been an increase in the marginal product of labour β. On the other hand, if the labour coefficient is interpreted simply as capturing the plant-size effect in a hedonic estimator of the average wage rate, these results indicate that the demand for type of skills present in large plants has increased or that these skills have become more difficult to obtain.[23]

The fact that the interaction term between the 1989 year binary variable and the numbers of technologies variable is only weakly significant does not mean that the effect of technology has remained constant over the decade–only that using the number of technologies without specifying the type of technology hides much of what is happening. As indicated previously, the inspection and communications as well as integration and control technologies have a greater effect on wages than the other technologies. Therefore, technology use was divided into two categories–the number of technologies used in inspection and communications as well as integration and control (NUMCOMM); the number of technologies from all other functional categories (NUMOTHER). These two variables along with the appropriate year interaction terms are included in column 2, Table 8. In 1981, the use of technologies in either set has about the same effect. But the 1989 interaction terms are significantly positive for the labour-enhancing technologies (NUMCOMM) and significantly negative for the second set (NUMOTHER). This confirms that the labour-enhancing technologies have been associated with increases in relative wage rates.

In order to test whether the effect of labour or of capital intensity has changed in direct proportion to the amount of technology being used, interaction terms–consisting of the number of technologies (NUMCOMM, NUMOTHER) in use times the labour variable and the capital-labour variable in 1989–are included. The coefficient attached to these variables measures whether the change in the effect of size or capital intensity has been particularly large in those plants that are using more advanced technologies in 1989. This could be the result either of their having added more technologies over the period or of a changing effect of advanced technologies on the wage rate.

[23] The latter is less likely since Freeman and Needels (1993) point out that skill differentials did not increase much in Canada during the 1980s.

Table 8. *Pooled data, Wage rates and technology use (weighted)*

Intercept	9.29		9.29		9.29	
Age	0.043	***	0.040	***	0.043	***
Foreign-owned	0.048	***	0.046	***	0.048	***
Innovative firm	0.069	***	0.071	***	0.070	***
Multi-plant enterprise	0.115	***	0.112	***	0.112	***
Technology Use						
Number of technologies in use (Number)	0.007	***	---	---	---	---
Year binary * Number	0.004	*	---	---	---	---
Number of Communications and Integration Technologies (Numcomm)			0.006	*	0.005	*
Year binary*Numcomm	---	---	0.018	***		
Number of Other Technologies (Numother)	---	---	0.007	**	0.007	**
Year binary*Numother	---	---	-0.010	**		
Year binary	0.063	***	0.067	***	0.064	**
Capital-labour ratio						
Log of capital-labour ratio	0.018	***	0.018	***	0.018	***
Year binary*capital-labour ratio	-0.013	***	-0.013	***	-0.014	***
Numcomm* binary *capital-labour ratio	---	---	---	---	-0.002	***
Numother* binary *capital-labour ratio	---	---	---	---	0.006	***
Plant size						
Log of plant employment	0.016	***	0.017	***	0.017	***
Year binary *log of plant employment	0.010	*	0.008	*	0.012	**
Numcomm* Year binary *log of plant employment	---	---	---	---	0.009	***
Numother* Year binary *log of plant employment	---	---	---	---	-0.016	***
F	167.29		97.41		87.68	
R-squared adj.	0.150		0.153		0.158	

** significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level*

These interaction terms are highly significant (Table 8). The coefficient on the 1989 capital-labour/technology interaction variable is negative for NUMCOMM but positive for NUMOTHER. The 1989 labour/technology interaction for NUMCOMM is positive and significant, but negative and significant for NUMOTHER. Once again, this can be interpreted to mean that labour productivity increased significantly where labour-enhancing advanced technologies were in use or that the demand for skills in larger plants has increased. In contrast, the reverse occurs for labour-saving technologies.[24] As was previously described, labour-enhancing technologies are used more frequently than are labour-saving technologies.

Thus, technologies that have been described as labour-enhancing can be said to have a labour-augmenting effect in plants that are advanced technology users[25] or to have increased the need for skilled workers in large plants. The wage of production workers has been increasing for those plants that have implemented these labour-enhancing advanced technologies, particularly in

[24] In the unweighted (large plant) sample, there is strong evidence of a positive effect of NUMCOMM on wages in 1981, a significantly greater impact in 1989 (a positive year interaction term) and the same differential effect of NUMCOMM and NUMOTHER on the marginal productivity of labour and capital as are reported in Table 8.

[25] Labour-augmenting change is associated with a production function of the type:
$Q = F(K, H(t)*L)$. When H is increasing in t, the marginal product of L increases over time.

larger plants. The increase is a function of the number of advanced technologies (in particular, the number of labour-enhancing technologies) that have been incorporated into the production process.

The analysis, to this stage, is constructed around a demand function for labour that is based on a simple but robust formulation of a production function. In order to examine the sensitivity of the results to a more complex form of the production function, a translog production function is substituted for the Cobb-Douglas and the resulting wage-share equation is estimated.

Assuming a translog production function of the form:

$$6)\ \ln Qi = A + \beta_0 \ln L_i + \beta_1 (\ln L_i)^2 + \alpha_0 \ln K_i + \alpha_1 \ln (K_i)^2 + \beta_2 \ln L_i{}^* \ln K_i$$

Then, the wage share equation can be written

$$7)\ W_{it} \,.\, Lit/Qit = \beta_0 + 2\beta_1 \ln L_{it} + \beta_2 \ln K_{it} \text{ or}$$

$$8)\ W_{it} \,.\, Lit/Qit = \beta_0 + (2\beta_1 + \beta_2) \ln L_{it} + \beta_2 \ln K_{it} /Lit$$

The plant characteristics (age, nationality of ownership, diversification of parent and industry environment) that were appended previously in order to capture efficiency or quality differences in the work force are also used here. Equation 8 was then estimated on the pooled data just as before, with number of technologies interacted with the 1989 year binary, with labour and with the capital-labour ratio. The results are reported in Table 9, both unweighted (mainly large plant) and weighted (population).

Table 9. *Pooled data, Wage share and technology use*

Variable	Unweighted		Weighted	
Intercept	1.47		1.45	
Age	-0.018	*	-0.020	*
Foreign-owned	-0.035	***	-0.046	***
Innovative firm	0.006		0.022	***
Multi-plant enterprise	-0.024	***	-0.080	***
Technology Use				
Number of technologies in use (Number)	0.001		0.005	***
Year binary * Number	0.011		-0.010	
Year binary	-0.033		-0.046	
Capital-labour ratio				
Log of capital-labour ratio	-0.107	***	-0.096	***
Year binary*capital-labour ratio	0.008	**	0.006	**
Number* Year binary *capital-labour ratio	-0.003	***	-0.001	
Plant size				
Log of plant employment	-0.012	***	-0.029	***
Year binary *log of plant employment	0.000		0.016	**
Number* Year binary *log of plant employment	0.003	***	0.003	**
F	448.6		395.8	
R-squared adj.	0.453		0.422	

** significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level*

The negative coefficient attached to the capital-labour ratio–β_2 (-.10)–indicates that capital and labour are substitutes. The positive interaction term of this same variable with the 1989 binary variable indicates that this substitutability declines over the 1980s–that labour and capital become more complementary. The parameter associated with the technologies/capital-labour interaction term is negative and tends, therefore, to reduce this effect–but only partially. The coefficient on the technologies size-year interaction term is positive and significant, thereby indicating that the impact of size on the marginal productivity of labour increases over the decade.

Extending the analysis to a more complex framework confirms that after taking into account these other factors, advanced technology has impacted positively on the share of the wage bill.

9. Conclusions

This paper has examined the extent to which advanced technology use is connected with higher levels of human capital in the work force. Earlier research suggested that technology use gives rise to higher skill requirements. These skill requirements are in sufficiently short supply that plants with advanced technologies implement special training programs to handle the skill deficits–programs that lead to higher training costs.

This paper has found that wages are higher in plants that adopt advanced technologies. This finding is robust to the research strategy employed. Whether simple tabulations of differences between the two groups are used, or multivariate analysis is employed, wages are related to technology use. After accounting for size, age, capital intensity, diversity and nationality, technology intensity is strongly related to the wage rates for production workers. Higher wages in technology-using plants reward higher innate skill levels that are required to operate the technologies and serve to attract those skills that are in short supply.

Equally important, the wage structure in 1989 is not the same as in 1981 for technology and non-technology using plants. Plants that use advanced manufacturing technologies in 1989 experienced greater increases in wages over the decade than those plants not using advanced technologies. This is particularly true of the new labour-enhancing technologies. More importantly, this increase is positively associated with size. Large technology using plants have increased their wages the most.

While this paper is not able to separate out the relative importance of the effects of higher technological intensity from a changing effect of technology on wages at the micro-level, it need not do so to conclude that skill-augmenting technology change at the aggregate level has been occurring. Skill-augmenting technological change occurs for the economy as a whole both when more plants adopt the advanced technologies that increase labour productivity and when the effect of technology on wages has increased. Either leads to skill-augmenting change associated with advanced technology use.

The association between technology use and wage growth that has been described herein may be a reflection of a technological revolution. New technologies are not introduced instantaneously. Their diffusion takes time. These data may simply trace out the trajectory that occurs as new technologies are introduced into the plant population. Equally, the association between technology use and changing wage differentials may be the result of a shift in the production function. The use of advanced technologies may have lead to an increased demand for more skilled labour.

While the diffusion or the production function story attributes a key causal role to technology, there are other explanations that attribute a reactive rather than a causal role to technology adoption. Increasing wage differentials could have been caused by an increased demand for relatively higher paid, more skilled workers--an increase in demand that is associated with changing trade patterns. Increased demand for skilled workers associated with growing trade between developed countries and lower wage developing countries would tend to increase wages for the relatively skilled and decrease them for the less-skilled. Higher wages in turn could have led to the adoption of more advanced technologies to replace higher skilled workers. This alternate explanation would also have seen increasingly higher wages being paid in establishments that started the decade with a wage premium. These establishments would have been those with higher initial levels of technology. They would also have increased technology use the most since the incentives to save labour costs would have been higher here. No attempt is made here to sort out the relative effect of technology and trade. This issue is addressed in an accompanying paper (Baldwin and Rafiquzzaman, 1996).

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